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ABSTRACT

This document introduces the aims and activities of the Intelligent Computer Aided Instruction (ICAI) research community situated within the Centre for Information Technology in Education (CITE) at the Open University in Great Britain, outlines the nature of the problems which come under the auspices of ICAI, and describes the research contribution being made in this area. The first of two sections presents a definition of ICAI and discusses its goals, methods of approaching ICAI, the current state of ICAI research, and the potential for expanded research in ICAI. The second section examines the existing ICAI community at the Open University, and describes the application of ICAI for teaching arithmetic, musical composition, and foreign language skills. Also outlined are research studies on problem-solving by students in physics, the analysis of structured tutoring dialogues, and other theoretically based issues in the application of artificial intelligence to education. The paper concludes with brief descriptions of the Open University as an environment for ICAI research and of the resources available for that research. A complete list of CITE reports is appended. (DB)

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Intelligent Computer-Aided Instruction research at the Open University.

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This document is intended to provide an introduction to the aims and activities of the Intelligent Computer-Aided instruction research community at the Open University. This group is currently expanding very fast and is probably already the largest centre outside the USA specializing in the application of AI techniques to educational domains. The group is situated within the Centre for Information Technology in Education, within the Institute of Educational Technology at the Open University. This document outlines the nature of the problems which come under the auspices of Intelligent Computer-Aided Instruction, describes the existing community and the research contribution which is being made to this area.

1. What is Intelligent Computer-Aided Instruction?

1.1 The goals of ICAI.

Intelligent Computer-Aided Instruction (ICAI) is the application of techniques and methodology drawn from Artificial Intelligence research to an educational domain. This involves using computers as a tool for developing and exploring theories about the process of education. Since these theories are embodied in computer programs, it follows that a well-developed theory also provides us with a computer which is able to teach.

One way of defining Artificial Intelligence is to suggest that it is an attempt to produce in a computer behaviour which, if performed by a human being, would be described as intelligent. ICAI may be thought of as an attempt to produce in a computer behaviour which, if performed be a human, would be described as "good teaching". This involves attempting to understand and build models of the processes involved in the teaching interaction, and creating programs which conform to those models.

There are a number of different possible goals which an ICAI researcher may have. These include understanding any one of a number of different aspects of the educational process, building psychological theories about teaching, and developing practical computer-based teaching tools aimed at tackling specific problems.

In discussing the use of computers as teaching tools it is important to remember that this term covers a range of possible activities - it is not a case of the computer standing up in front of a group of people and lecturing! There are a large variety of educational approaches which impose different constraints on the pupils and have different expectations of the pupil: each of these should be represented in computer tutors. The range of activities includes things which are not commonly regarded as "teaching" in the current sense, such as providing a supportive environment for discovery learning.

Why should an attempt be made to produce such computer-based tutors? On the pure research level there is the desire to understand more about the processes which contribute to an educational interaction. On a more applied level there are a number of things which can be achieved using computer-based tutoring which cannot be achieved with human teachers (given existing economic and social constraints). One of the primary advantages is the possibility for providing one-to-one teaching interactions. There can be no doubt that individual tuition, tailored to the

requirements of each learner, is the most effective and rewarding form of educational interaction (for most domains). Since our educational system has, of necessity, become oriented towards group teaching, many of these advantages have been lost. Intelligent computers can provide individualised tutoring without the necessity of losing the group teaching environment and the advantages which it also offers. A computer used in this way can provide immediate feedback to the user on the task which they are performing. The immediacy of this response is crucial, because teaching is most effective when occuring in direct response to a need of the pupil.

1.2 Methods of approaching ICAI.

Before outlining the methodology used in research on ICAI systems, it is worth pointing out the difference between such systems and uses of non-intelligent computer software in an educational setting. The latter approach is commonly called CAL (computer assisted learning) or CBT (Computer Based Training). The most common approach to CAL involves collecting experts in the domain being taught and embodying their knowledge in a special program for teaching about that domain. This knowledge is reorganised into a structure of lessons (or "frames") which correspond to the sequence of learning experiences which the designers believe are suitable to the pupil. The process of forcing a rich domain representation into this rather artificial structure (normally based on linear presentation of text or simple branching mechanisms) is erratic and extremely time-consuming for those involved. Since such systems have little or no capacity for adaption, it forces every pupil to undergo the same essential teaching sequence (which is unlikely to be appropriate for any but a small percentage of pupils). If an event arises during the use of the program which was not explicitly anticipated by the program designer, then the system is unable to cope usefully with it. Other forms of CAL also suffer from these two major deficiencies (the lack of pupil modelling and the lack of a deep, explicit domain representation).

An ICAI system operates at a more abstract level than this. Attention is paid to the high-level representation of knowledge about a domain (with no reference to how it is taught), to representing possible teaching approaches, possible problem-solving methods, possible mechanisms for creating models of the current state of the pupil etc. These higher level components are then combined in a manner which facilitates generation of the teaching sequence as the teaching is being performed. Since this generation is occuring online during the educational interaction, and uses information specific to that interaction (such as beliefs about the current state of the pupil and the current focus of the interaction), such generative systems provide adaptive interactions, adjusted to the requirements and needs of each pupil.

By distinguishing the variety of components used in a teaching system the flexibility of the software is increased. In traditional CAL, the model of teaching is implicit in the structuring of the materials, and moving to a new domain will essentially involve generating a new domain-specific representation for the same theory. If this teaching model can be separated from the rest of the system then changing domain simply involves changing the domain-specific knowledge: the same teaching model can be used in all domains.

Approaching teaching from an AI viewpoint involves the generation of large and complex programs which explore aspects of the teaching process. There is a large theoretically driven component, but also, since no-one has a great deal of experience with computer-based teaching of this type, there is scope for empirical studies conducted within this framework. These studies provide the data which is necessary as a basis for further development in tutoring systems.

1.3 Current state of ICAI research.

ICAI has existed by name for only a few years, but AI programs tackling these educational problems have existed for much longer. The first such program of interest is "Scholar" developed in the late 1960's by J.R.Carbonell. This system focussed on maintaining a mixed-initiative natural language-like dialogue between the pupil and computer. Since this time many other systems have been developed, each focussing on some specific domain or some specific aspect of the educational process. Important among the existing systems are GUIDON (which demonstrated that an expert

system is not a sound basis for tutoring), WEST (which introduced the idea of tutorial guidance) and SOPHIE (which covered many areas of research and was used by the US navy for some time). Systems developed by current members of the ICAI team at the OU include a self-improving quadratic tutor (Tim O'Shea), a programming tutor, IMPART (Mark Elsom-Cook), and a production rule user modelling system POPSI (Rick Evertsz). These systems were all developed as laboratory research tools rather than practical teaching aids.

In the last two years more powerful microcomputers have become available at reasonable prices. For the first time, these systems make attempts to develop tutoring systems which can be applied in a practical environment feasible. The possibility of such research is helping to develop a broader base for ICAI research.

From this it should be clear that there are two main streams of development which are currently required in ICAI. One of these is the need to explore the problems of building practical teaching tools based upon existing technology, the other is the need to expend considerable effort on the basic research which will allow such transfer to continue to develop and to fulfill the promise of ICAI. These areas are closely interrelated and should be expanded in parallel. Data from the empirical work provides a starting point for theoretical developments, and theories can be tested in the environments which practical systems provide. There can also be a direct improvement in the quality of practical systems which derives from the close linking of these research strands.

In the past, most of the tutoring system research has been carried out by single individuals or small groups. As was mentioned above, the interdisciplinary nature of such systems is better suited to development in environments containing larger teams with complementary skills and specialities. The two largest ICAI research groups in the world (Xerox PARC and Bolt,Beranek and Newman), are both based at commercial sites in the USA.

1.4 Current potential for expansion and exploitation.

ICAI research has progressed slowly since the first systems were designed in the early 1970's. Since that date a handful of systems have been produced, each making a small contribution to this area. The major reason for the small scale of developments in this field has been correspondingly slow progress in areas upon which ICAI depends. This situation is changing and, in consequence, the time is now ripe for making a major research and development effort in the area of ICAI.

To illustrate this development of the enabling technologies, consider two areas on which ICAI depends strongly: models of learning processes and facilities for generation and comprehension of natural language. Psychology has found difficulties in producing formal models of learning, and machine-based models were heavily tied to their neurological origins. Since 1980 this has changed, and there has been a vast expansion of research on machine learning. Such research provides exactly the formal models of learning which are required by an ICAI system.

Natural language understanding was considerably advanced by the work of Winograd in the 1970's. This, like much work before it, was strongly oriented towards studies of the syntactic structure of language. Since 1979 there has been increasing interest in AI given to more human-like issues in the pragmatics of language, such as the way that the structure of a conversation may affect the meaning of an utterance. This work is also having an effect on producing human-computer interaction mechanisms which do not rely directly on language generation and comprehension, but which are nonetheless closely modelled on human dialogues.

It is common for AI research to be directed towards goals which are not achievable in the short-term, but which provide some short-term rewards. This is certainly the case in ICAI: a full stand-alone tutoring system is not achievable with existing technology, and it will require some time and further fundamental research before such a system becomes possible. In the shorter term however, such research can produce systems which can make a valid contribution to parts of the educational experience. For example, tools for thinking about course structure, simple adaptive CAL, automatic problem-generation, advising programs and intelligent help systems are all possible as short-term outcomes of ICAI research.

In commercial terms, the need for ICAI systems is huge. On-line teaching packages are becoming more common in industry. It is estimated that the current CBT market in the UK is of the order of £10-15 million. By providing a better quality teaching system through ICAI, demand for these systems will increase still further, and the educational value of the interaction can be improved. At present industrial training in the USA costs approximately $8 billion per annum, and it is believed that computer based teaching can save about 30% of those costs. One of the ICAI team's industrial collaborators recently pointed out:

> " Most computer-based products could be improved by incorporating an expert tutorial system into them. What we need is for the academic community to provide the appropriate basic and applied science which we can incorporate into commercial products."
>
> Keith Shaw, Managing director, System Ltd.

Although the application of such packages applies across all subjects, the primary growth at present is probably in the use of these aids for teaching about computing, since computer systems are developing so quickly at present.

2. The existing ICAI community at the Open University.

2.1 Members of the ICAI community.

At present there are three groups at the OU (with considerable overlap of membership) which are involved in aspects of the educational use of computers. The Centre for Information Technology in Education contains experts in many aspects of this field, including uses of video-disc technology, computer-based text production and traditional CBT methodology. The Computer Assisted Learning research group includes people who are more oriented towards an AI approach to the use of computers in education, as well as researchers involved in issues such as the implications of new technology for the role of women. The Human Cognition Research Laboratory focusses on more general AI research, but includes staff with research interests in modelling novice programmers, and in building tools to help the process of learning to program.

Researchers in ICAI are drawn from all these groups, although the predominant influence is from the Centre for Information Technology in Education. At present most researchers with ICAI interests can devote only a part of their time to work in this area, so although there are approximately 20 people on campus with interests in this area, only about 14 of those people spend 100% of their time involved in ICAI. The centre includes some of the best known ICAI researchers outside the USA, and has a strong record of academic publication. Current full-time ICAI researchers in the Centre for Information Technology in Education are:

Prof.Tim O'Shea
Dr. Mark Elsom-Cook
Ms. Ann Jones
Ms. Eileen Scanlon
Mr. Rick Evertsz
Dr. Sara Hennessey
Mr. Mike Fox
Mr. Simon Holland
Ms. Patricia Fung
Mr. Philip Swann
Mr. Alistair Edwards
Mr. Michael Baker
Ms. Kate Stainton-Ellis
Ms. Fiona Spensley

2.2. Current projects in ICAI.

Research on ICAI at the Open University is expanding quickly, with a number of projects commencing in 1985/6. These projects vary from explorations of theoretical issues in the application of AI methods in education to more practically oriented projects which are intended to produce useful teaching aids using existing technology. It was mentioned above that ICAI is being recognised as an area which is currently appropriate for expansion, and this is reflected in the variety of sources from which the projects listed below are funded.

a) The intelligent arithmetic tutor project.

This project has the goal of producing a tutor for the basic arithmetic skills. This tutor is intended to be available on a microcomputer (the Apple Macintosh). One aspect of the approach taken is to conduct an empirical study of misconceptions about arithmetic which children may have, and to store this specialized knowledge as a collection of rules. Since these rules are ones which result in errors in arithmetic problem-solving, they are known as "bugs" or "malrules". There exist corresponding correct rules which someone with an accurate knowledge of arithmetic would possess. By examining the arithmetic problems which a particular child can tackle, the system attempts to build a "model" of the set of rules which that child is using, and can therefore identify exactly which rules are faulty and embark on appropriate remedial aid for the child.

Work is in progress on the use of machine learning techniques to directly infer the rules, rather than simply choosing from a pre-stored set. The tutor interacts with the pupil via a set of mathematical microworlds designed to support a number of forms of mathematics (such as informal reasoning approaches).

This project, which is funded by ALVEY, is of 3 years duration and involves 5 staff at the Open University (Tim O'Shea, Ann Floyd, Rick Evertsz, Sara Hennessy, Mike Fox). The project is conducted in collaboration with System Ltd.

b) ICAI in the arts.

This project involves a number of related studies, which are focussed on the application of ICAI for teaching courses in music and languages.

One aspect of the project investigates the use of computers in teaching music composition skills. By combining computing with new musical technology (such as synthesizers and sequencers) an environment is being developed in which students can learn about music by directly experiencing their own attempts at composition. The computer acts as a tool for controlling the music, and as a "guide" with expertise about music, who prompts the pupil along interesting paths of discovery. A related aspect of the project is investigating the nature of musical performance skills and mechanisms for teaching pupils about musical interpretation. In the performance work, the pupil has control over the music similar to the control which a conductor has over an orchestra. The computer supports the pupil in learning to hear and generate particular interpretations of a piece of music.

Another part of the investigation involves attempting to build a model of the grammatical misconceptions which may arise when Italian-speakers are taught english. This very specific domain provides an environment in which issues of user-modelling can be explored. It is also a source of empirical data, since the project includes a longtitudinal study of english learners at a school in Italy.

The third part of the project involves examining two existing undergraduate courses at the OU and attempting to build an explicit formal representation for the structure which is implicit in the teaching materials. Making this structure explicit is a first step towards making it manipulable, which is a necessary prerequisite for building generative tutoring systems.

The project is a collaborative study with the departments of music and language at the OU and is funded by internal OU funds, SERC and ESRC. It involves 6 people (Mark Elsom-Cook, Simon Holland, Philip Swann, Trevor Bray, Geoffrey Warner, Tim O'Shea, Michael Baker).

c) Data-driven tutoring system design.

There are a number of existing intelligent tutoring systems which are very similar when examined in detail, but which are difficult to compare directly because of the differences in their implementation. A major goal of this project is to bring these systems together by reimplementing them in a common framework and examining the effect of the design decisions taken in each system. This will help to consolidate the base for further development of tutoring sytems.

The systems being unified here are all based around rich knowledge structures associated with a particular domain. A second goal of this project is to examine the knowledge representation issues of these systems in the light of previous work on educational curriculum design.

The project is funded by SERC, and the research is being conducted by Mark Elsom-Cook.

d) Structured tutoring dialogues.

The central feature of an Intelligent teaching interaction is a dialogue between the pupil and teacher designed to fulfill certain educational goals. This project draws on recent research in AI models of conversation in order to build better models of such dialogues. The project is based around the analysis of a set of computer-mediated teaching interactions. The research has implications for the more general aspects of user interfacing.

The project is funded by the ESRC, and involves 2 staff (Kate Stainton-Ellis, Mark Elsom-Cook).

e) Models of programmers.

Several investigators work in this area, with slightly differing approaches. Large empirical studies have been conducted (by Tim O'Shea and Ann Jones) which attempt to elicit models of the programming behaviour of novices using various languages, and this has provided the basic data to be used for developing models of the conceptual structures which these students are using in programming. Mark Elsom-Cook has taken the complementary approach of developing highly formalized mathematical/computational models of expert programmers. Pat Fung is using formal program semantics to attempt to model some of the empirically observed behaviour.

Funding is from the OU. Staff involved are Pat Fung, Ann Jones, Mark Elsom-Cook, Tim O'Shea.

f) Models of physics problem-solving.

The domain of simple physics provides a rich area in which to develop models of students' understanding. Eileen Scanlon and Rick Evertsz have both carried out considerable research in this field aimed at building production rule models of physics problem-solving behaviour. Strong links in this area are maintained with Oxford polytechnic, and discussions are currently in progress with regard to the possibility of applying this research to existing OU physics courses.

g) Tutoring procedural skills.

This project is undertaken with an industrial collaborator (ITT) who is currently funding the project. It is a development project for providing a real tool which can be used in the training programme of companies marketing high technology products, satisfying a need for distance teaching of procedural skills which cannot be adequately met in other ways. A prototype system is already available, and the next 2 years involve field testing and developing the system.

Funding is from ESPRIT. OU staff involved are Fiona Spensley and Mark Elsom-Cook.

The project is being conducted jointly with ALCATEL ESC and DATAMAT (Italy).

h) ECAL system.

The ECAL system is a hybrid tool based around adding some AI features to a traditional authoring language. The aim is to produce a toolo for writing computer-based material for OU courses which is adaptive, without forcing coursewriters to move a long way from the skills needed to write a book.

Staff involved are Mark Elsom-Cook, John Naughton, Phil Butcher and Kate Stainton-Ellis.

j) Tutoring on OU courses.

The nature of the OU requires much teaching to be done at a distance. There are a number of small projects aimed at satisfying particular needs of courses which have difficulty teaching via other media. (For example, music performance skills are very difficult to teach remotely, but computer-based methods can help). Currently, we are investigating teaching basic numeracy, quantum physics, Artificial Intelligence, music harmony and composition skills using ICAI methods.

2.3 The OU as an environment for ICAI research.

The Open University provides a highly appropriate environment in which to carry out research and development on Intelligent Computer-Aided Instruction. The university has always been world leader in the field of distance teaching. Provision of such teaching is achieved using a mixture of carefully prepared texts, television programmes, radio programmes and tutoring via telephone or personal contact. New developments in information technology provide the basis for bringing about improvements in the nature of remo e teaching. Facilities for remote contact via networking and electronic mail will provide much closer contact between students and staff involved in the production of various courses. Tools derived from ICAI research can be provided in the home of each student to enhance their learning. This aspect of the Open University's situation provides a practical base on which working ICAI systems can be developed. As a first stage towards embracing these technologies, the Open University has agreed a policy of ensuring that every student has access to a microcomputer, and has decided a specification for that computer which facilitates the immediate development of software.

These groups provide a supportive environment in which ICAI research can be conducted. The OU group maintains strong contacts with other groups: both academic and commercial. Close ties with the AI groups at Sussex, Edinburgh, Warwick, Cambridge APU, Leeds and Lancaster exist, as well as with many european and American universities. Industrial links include System, Alcatel, ATTA and Apollo Computers in the UK, as well as Xerox PARC, Digital and Bolt,Beranek and Newman in the USA.

The ICAI team in the Institute of Educational Technology received the largest ALVEY/SERC grant for ICAI, was awarded the only "new blood" lectureship in this field, and provided the Alvey directorate with the ICAI theme manager.

2.4 Resources for ICAI research.

At present the hardware available for research in ICAI is tied to specific projects. The central computing resource is a network of Apollo Domain workstation systems which provide each user with high quality graphics and access to software such as standard AI languages (Common Lisp, Quintus Prolog), ordinary procedural languages (Pascal, C, Fortran etc) and specialized interface building tools. Other computing provision includes a Xerox 1109 system and a number of Apple macintosh microcomputers. Through HCRL, access is also available to Symbolics, TI explorer and VAX systems.

The ICAI group is building up a base of software from other centres working in related areas which enable detailed studies of previous systems to be made. Current acquisitions include the TRILL and PROUST tutoring systems, as well as a large range of music tutoring software.

CENTRE FOR INFORMATION TECHNLOGY IN EDUCATION

List of CITE Reports

These reports may be obtained from:

Hansa Solanki, Institute of Educational Technology, The Open University, Walton Hall, MILTON KEYNES, MK7 6AA, England.

Report No.	Title and Author
1	A.T. Vincent, (1985) Computing and the Blind.
2	A. Jones, G. Kirkup, J. Morrison (1985) A Trial of Home Based Computer Terminals.
3	Gill Kirkup, (1985) The Present and Potential Use of Ceefax in the Open University.
4	Mark Elsom-Cook, (1986) Artificial Intelligence and Computer Assisted Instruction.
5	Mark Elsom-Cook, (1986) A Pascal program checker.
6	Simon Holland, (1986) How computers are used in the teaching of music and speculations about how Artificial Intelligence could be applied to radically improve the learning of composition skills.
7	Simon Holland, (1986) Design consideration for a human-computer interface using 12-tone three-dimensional harmony space to aid novices to learn aspects of harmony and composition.
8	Alison Petrie-Brown, (1987) The Influence of Context and Coherence as a Foundation for Dialogue Research.
9	Eileen Scanlon, Randall B. Smith (1987) A Rational Reconstruction of a Bubble Chamber Simulation Using The Alternate Reality Kit.
10	Mark Elsom-Cook, (1987) Intelligent Computer-Aided Instruction research at the Open University.